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Raman scattering in strained highly-doped p-type GaAs/GaAsP epitaxial layers

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Strained GaAs epitaxial layers and GaAs-based superlattices are known to be very effective as photoemitters of highly polarized electrons [1]. The efficiency of the polarized electron source is determined both by the maximum value of electron polarization and the quantum yield at the maximum, which depend on the thickness of the active semiconductor layer and the valence band splitting, induced by the layer strain. Therefore it is essential to have highly strained layers with sub-micron thicknesses. To produce high valence band splitting the value of the elastic strain in the GaAs active layer no less than 1% is needed. At such elastic strains the value of the critical thickness of a GaAs strained layer at which the misfit dislocations begin to introduce into the film and plastic relaxation occurs is about 10–20 nm, so that submicron layers are partially relaxed [2]. The relaxation causes inhomogeneous distribution of the dislocation density and the strain in the layer depth. Besides, to obtain negative electron affinity, the layers are highly doped with the acceptor impurities. The efficient control of the parameters of the layers becomes a difficult problem. Raman scattering is found to be effective to solve the problem.

We have studied GaAs strained quantum layers grown on relaxed [001] $GaAs_{1-x}P_x$ buffer layers using MOCVD. The incorporation of tensile strain was made possible by preparing a 1-μm-thick Ga $As_{0.3}P_{0.7}$/GaAs superlattice grown in its turn on [100] GaAs substrate which was followed by a $GaAs_{1-x}P_x$ buffer. The strain of the GaAs was measured using X-ray diffraction, Raman spectroscopy and photoluminescence.

The polarized Raman spectra of the samples with varying thickness and substrate composition were measured at room temperature with back-scattering geometry for several excitation lines of an Ar-ion laser. The Raman spectra of GaAs 0.15-μm-thick films at $GaAs_{1-x}P_x$ buffers with $x = 0.1$, 0.25, and 0.3 are presented in Fig. 1. The full width at half maximum (FWHM) of the LO line in the layers with $x \leq 0.2$ is found to be considerably larger than that of the undoped GaAs strained and unstrained reference layers. The frequency and the width of the LO-band depends strongly on the buffer composition: when the composition increases above $x = 0.2$ the full width at half maximum of the LO line decreases rapidly.

In Fig. 2 the Raman line shift and the FWHM are plotted as a function of the buffer P — content for 0.1-μm and 0.3-μm-thick layers. In both cases a narrowing of the Raman line accompanied by the low energy-shift is observed. Theoretical analysis showed that the evolution of the Raman spectrum is due to the self-energy effects in the LO phonon spectrum which originate from intersubband heavy-hole to light hole transitions caused by deformation potential-type interaction. The LO phonon line narrowing occurs when the strain-induced valence band splitting exceeds the LO phonon frequency. The

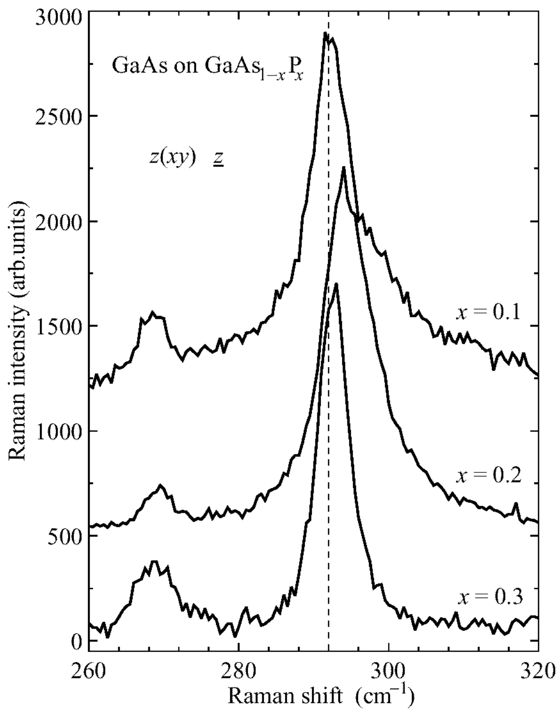

Fig 1. Raman spectra of the 0.15-μm-thick GaAs layers for several buffer (substrate) compositions changing the layer strain.

low-frequency shift observed with the narrowing is caused by the growth of the hole-transitions contribution to the LO phonon softening at the edge of the intersubband hole transitions.

The changes in the LO phonon Raman line are sensitive to the strain inhomogeneity in the sample in the light absorption depth. We used it to evaluate the strain relaxation. We have found the strain relaxation of about 80% even at small misfits ($x = 0.1$) and the layers thickness 0.1–0.2 μm while the narrowing at $x \geq 0.2$ observed for different excitation lines shows that the strain remains large and homogeneous even for $x = 30\%$ and 0.2 μm-thick layers. The estimates of the critical thickness t_c for $x = 30\%$ (the lattice mismatch $\epsilon = \delta a/a = 1.02 \times 10^{-3}$, where δa is the lattice constant's difference between the GaAs epilayer and GaAsP buffer substrate) according to relation of Ref. [3] gives $t_c \approx 9.8$ nm. Still the strain remains high even for the layers having the thickness 20 times larger than the critical. Our observation is consistent with previous findings [4] obtained from the polarized electron emission studies accompanied by the X-ray diffraction patterns analysis.

The asymmetry ($\Gamma_{\rm low}/\Gamma_{\rm high}$) of the GaAs LO line remains constant for $x \leq 0.2$, therefore it indicates the predominant contribution of the intersubband transitions to the LO line broadening.

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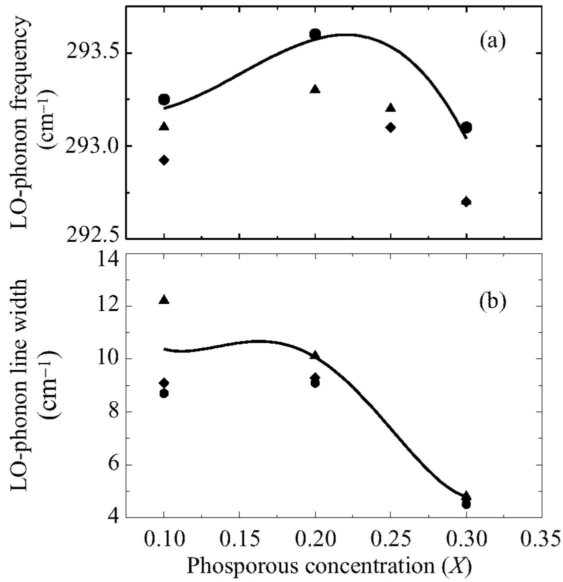

Fig 2. Raman LO-ponon line shift (a) and full width at half maximum (b) in GaAs epilayer on $GaAs_{1-x}P_x$ substrate as a functions of the phosphorous concentration x, points — layers of different thicknesses, lines — calculations.

TAS (project No. 94-1561) and by RFBR (Grant No. 96-02-19187a) is also gratefully acknowledged.

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